Positioning with single and dual frequency smartphones running Android 7 or later.

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For many years, low-cost GNSS receivers have been providing meter-level positioning to the mass-market. In particular, most smartphones are nowadays at least GPS-enabled but many high-end devices are also GLONASS- and Beidou-enabled. At the present time, only a few smartphones are Galileo-enabled.

During its “I/O 2016” held in May 2016, Google announced that the raw GNSS measurements collected by devices running Android 7 would be made available to users. Up to Android 6, only position fixes and limited satellite information (PRN, azimuth, elevation, …) were available. This announcement opens new opportunities. Indeed, the development of new data processing strategies might lead to decimeter-level positioning capabilities allowing the emergence of new applications, in particular in the field of location-based services.

The paper analyses the quality raw GNSS measurements (GPS, GLONASS, Galileo, Beidou) provided by 5 multi-GNSS smartphones (single frequency: Samsung S8 and S8+, Huawei Mate 9 and Mate 10; dual frequency: Xiaomi MI 8) and compares them with geodetic quality measurements. Then, smartphone positioning performances are evaluated using different algorithms.

In order to collect the raw measurements, we used the “GnssLogger” application kindly provided by Google. This application creates ‘.txt’ data files which contain different information: GPS time of measurement, constellation, satellite number, carrier-to-noise-density ratio, time of emission (which together with time of measurement allows to compute code pseudoranges), code range rate (coming from Doppler), phase pseudorange, information about cycle slips, multipath, ….

Since December 2016, we have been regularly collecting static raw data samples on the roof of our building where we are operating 6 geodetic reference receivers (2 Trimble NetR9, 2 Septentrio PolaRx4, 1 Septentrio PolaRxS and 1 Septentrio PolaRx5) which are connected through 2 splitters to 2 Trimble choke ring antennas allowing a comparison between smartphone and geodetic GNSS raw data. In addition, a geodetic quality field receiver (Trimble R10) has been used to provide “ground truth” for the different smartphone locations used on our roof. As our roof has an open sky, we can consider it as an “ideal” case. All the results presented in our paper have been obtained using self-developed software.

As far as raw GNSS measurements are concerned, 2 major differences between smartphones and geodetic receivers can be mentioned. On the one hand, unlike geodetic receivers, smartphones provide pseudorange measurements before the TOW has been decoded. Therefore, these pseudoranges are “ambiguous”. In the case of GPS, GLONASS and Beidou, unambiguous pseudoranges are usually obtained a few minutes after a cold start but in the case of the more complicated Galileo signals, code pseudoranges often remain ambiguous during much longer periods. For this reason, we implemented a simple technique to solve the code ambiguity.

On the other hand, phase measurements collected by smartphones are not continuous due to the so-called duty cycle. Nevertheless, after a cold start, we have been able to collect continuous periods ranging from 5 to 15 minutes allowing us to exploit phase measurements both for the assessment of data quality and for the evaluation of positioning performances.

In a first step, we analyse data quality (C/No, number of satellites tracked, precision, multipath, clock behaviour) for the different smartphones considered in our study. Even if satellites can be tracked from 0° elevation, we applied a 10° mask; for our location, this means that QZSS satellites, which have been track by our smartphones, have not been considered as they remain below 10°. We assess the observable (code, phase, Doppler) quality by forming different combinations: code minus phase, code range rate minus phase range rate, Doppler range rate minus phase range rate, between smartphone and between geodetic receiver and smartphone short baseline double differences. Results obtained with the different combinations using more than one year of regular data collection are consistent. As illustration, code pseudorange precision (1σ for elevations larger than 10°) for Samsung Galaxy S8 depends on the considered GNSS: GPS (3.1 m), GLONASS (6.5 m), Galileo (2.6 m), Beidou 2 and Beidou 3 IGSO and MEO (2.1 m). Our Huawei Mate 9 gave similar results. Based on the data processed so far, Beidou and Galileo code pseudoranges have the best precisions. This is promising as more Beidou MEO and Galileo satellites will be launched in the near future. In our “ideal” static case study, we observed moderate (few meter level) multipath even if we found a few satellites (GPS and GLONASS) with multipath amplitude up to 40 m.

In a second step, we assess the performances of different multi-GNSS positioning techniques: Single Point Positioning (SPP) with standard Least-Square, SPP with Kalman Filter using velocity information from Doppler observable, SPP with Doppler- or carrier-smoothed code, code DGPS and RTK using our geodetic receivers as reference stations. First results show that short baseline DGPS with carrier-smoothed code (Kalman filter) provides sub-meter positioning precision (1σ).

Finally, we compare the results obtained in our “ideal” static case with pedestrian and car navigation.